eRD103: High-Performance DIRC (hpDIRC)

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The objective of the remaining R&D program proposed below is to validate the PID performance of a cost-optimized hpDIRC design for the EIC project detector with a vertical-slice prototype in a particle beam by FY24.

All three currently proposed EIC central detector designs consider the hpDIRC as the leading option for barrel PID. Independent of the details of the design of the overall EIC detector, several important aspects of the hpDIRC design still need to be studied and verified to ensure that the required performance can be achieved, to minimize risks and to realize opportunities. Key topics include: the usability of BaBar DIRC bars, the development of compact readout electronics for the fast detection of single photons with high-density sensors, and the validation of the PID performance of a cost-optimized design.

The proposed R&D targets these issues in three stages to come to clear decisions by the end of FY24. The first stage focuses on the validation of the disassembly of the BaBar DIRC bars, the performance and cost optimization of the design in simulation, and the development of the readout electronics. Assembly and tests of the hpDIRC prototype will start in FY22 by integrating tracking and timing detectors with the prototype in the Cosmic Ray Telescope at SBU in preparation for the first beam test at Fermilab in the second stage, in FY23. In the final stage the upgraded hpDIRC prototype, with the final configuration of optics, sensors, and readout electronics, will be tested at Fermilab to determine the key performance parameters and decide on the final design.

1 R&D plan for FY22

hpDIRC Prototype Development

A new Cosmic Ray Telescope (CRT) setup is being planned at SBU to be used for initial tests and performance studies of the hpDIRC prototype as well as the evaluation of the commercial small-pixel MCP-PMTs and Hawaii electronics with Cherenkov photons. The CRT will include tracking and timing detectors that will be part of the hpDIRC prototype setup for future beam tests at Fermilab. The SBU group will take the lead on setting up the CRT setup with contributions from the CUA, GSI, and ODU groups. Funds requested by SBU will be used for the acquisition of a 2k-channel readout system based on the VMM3 chip and SRS, the hardware of the assembly structure, and the gas supply necessary for the CRT tracker system.

The modular design of the EIC hpDIRC prototype, inspired by PANDA Barrel DIRC prototype, will allow work to start immediately, once the components are transferred from GSI, Germany. The components include optics (bars, plate, prism, lenses) and several Photonis XP85012 MCP-PMTs with a pixel pitch of 6.5mm and matching readout electronics. This setup can be used to develop mechanical aspects of the prototype, to integrate the tracking and timing detectors with the hpDIRC prototype in the SBU DIRC lab, and to develop the required DAQ code and tracking algorithms using cosmic event data. This will ensure the **hpDIRC prototype system readiness** for the beamtest at Fermilab in FY23. Funds requested by CUA will cover power supplies, computing and alignment components.

In parallel to the work in the SBU DIRC lab a lot of effort will go towards developing **a working combination of small pixel sensors and a fast readout system to match the required timing precision**. The only commercially available MCP-PMT candidates with pixels sizes of 3.5mm or less are the PHOTONIS XP85122-S and the Photek MAPMT 253. One of each sensor type was purchased as part of generic R&D (eRD14) and the UH and Nalu group plan to combine them with the ASIC readout electronics they developed. The completed readout units, after initial tests at UH/Nalu, will be tested with a picosecond laser pulser and cosmic rays in the SBU DIRC lab. Funds are requested by UH for fabrication costs, based on engineering estimates and similar development efforts at UH, and for provided equipment and engineering support from Nalu Scientific. It should be noted that this activity could be funded and coordinated via the eRD109 proposal, instead of via eRD103, as long as the funds are available in time.

The mid-term goal of the proposed hpDIRC R&D is to assemble an **EIC DIRC prototype with small pixel-size sensors and readout electronics**, capable of validating the simulated performance and to directly measure the PID performance with a mixed hadron beam in FY23. If the 32x32 channel version of the 10cmx10cm Gen III HRPPD becomes available in time, the next step would be to instrument one half of the prototype readout plane with HRPPDs and the other half with commercial small pixel MCP-PMTs to directly compare the sensor performance and evaluate the required detector plane coverage. All sensors envisioned for the FY23 prototype, preferable both the commercial MCP-PMTs and the HRPPDs, would have to be in hand several months before a scheduled beam test to evaluate the sensors in the lab and to validate the performance in combination with the readout electronics prior to the 2023 beam test. **This means that procurement of a sufficient number of small-pixel sensors should be initiated by the summer of 2022**. The requested budget would be sufficient to cover 2/3 of the readout plane with commercial small-pixel MCP-PMTs.

SLAC and JLab are in the process of starting the effort to disassemble the BaBar DIRC bar boxes, to extract the bars and to transport them to the East Coast in FY22 for future use in the EIC hpDIRC. Funding for this activity is expected to be provided by JLab. If those bars are of high optical and mechanical quality, reuse of the BaBar DIRC bars could reduce the hpDIRC cost by 30-50%, depending on the details of the design. **Measurements of the mechanical and optical quality of the surfaces are of critical importance to decide if the disassembly results in bars of a sufficiently high quality.** An optical DIRC lab at JLab or ODU will be needed to evaluate a significant number of bars after disassembly. The work to set up the optical lab should start in early 2022 to be in position to perform the measurements in time to provide fast feedback to the disassembly team. Note that this lab will be required independent of the ultimate choice to use reused BaBar DIRC bars or new bars, since newly produced bars will require the same type of QA scan procedures to validate the fabrication process. The Postdoc requested by ODU would be responsible for setting up the lab and for performing the bar scans specifically for the BaBar DIRC bar reuse. Funding for the DIRC lab equipment is being discussed with JLab management and included in this proposal funding request in case JLab funding should be unavailable.

Software Development

The two main open design questions for the hpDIRC that need to be studied in simulation in FY22 are (a) how many sensors are required to cover the detector plane and how should they be arranged and (b) are short narrow bars or a short plate the better option for coupling the BaBar DIRC bars to the prism and what type of focusing delivers the best performance? Both issues have a significant impact on the cost of the hpDIRC and a decision should be made by FY23 to prepare the hpDIRC prototype for design validation in FY24.

Summary of Proposed Activities

Software:

- Compare the performance of different hpDIRC geometries (radiator bar size, focusing, prism shape, MCP-PMT arrangement, bar-plate hybrid optics).
- Study the hpDIRC performance with background in the full EIC project detector implementation.
- Develop tracking and event timing software for Cosmic Ray setup.
- Complete the prototype simulation, evaluate the expected performance with cosmic rays and particle beams, and determine the requirements for supplemental beamline instrumentation.

Hardware:

- Assemble the initial hpDIRC prototype with tracking and timing detectors in new Cosmic Ray setup.
- Commission detectors, electronics, and DAQ with cosmic rays.
- Prepare first set of small-pixel MCP-PMTs with matching readout electronics, test them in Hawaii and with the hpDIRC prototype at SBU.
- Procurement of small pixel sensors for hpDIRC prototype beam tests in FY23 and FY24.
- Evaluate the optical and mechanical quality of the DIRC bars after the BaBar DIRC disassembly.
- Incrementally upgrade the prototype based on available components (sensors, readout electronics).

2 Manpower required and available for FY22

The proposed R&D program will be carried out by collaborative effort of CUA, Erlangen University, GSI, JLab, ODU, SBU, UH, and USC, which includes all the hpDIRC experts from eRD14.

Significant in-kind manpower contributions from: Dr. Klaus Dehmelt (SBU) Dr. Roman Dzhygadlo (GSI), Thomas Hartlove (ODU), Dr. Charles Hyde (ODU), Dr. Greg Kalicy (CUA), Dr. Albert Lehmann, (EU), Dr. Maria Patsyuk (JINR), Dr. Carsten Schwartz (GSI), Dr. Jochen Schwiening (GSI), Dr. Gary Varner (UH).

Dr. Nilanga Wickramaarachchi was hired as a Postdoctoral researcher at CUA with 50% support from the generic R&D program. Maintaining the support of his position will be crucial for success of the proposed hpDIRC R&D program, in particular the simulation and reconstruction tasks.

Funding is requested for Postdoctoral fellow Dr. Shivang Tripathi to work on the design and fabrication of an interface board to mate the photosensors to the Nalu Scientific-provided readout ASICs and backend connection cards.

Funding is requested for a PostDoc for ODU to set up the DIRC lab for QA of the disassembled BaBar DIRC bars and to perform the QA measurements. A qualified and experienced candidate is available at ODU.

3 Milestones for FY22

- Optical DIRC lab for BaBar DIRC bar QA ready (JLab/ODU, Q2/2022)
- Assembly of Cosmic Ray Telescope in SBU DIRC lab complete (SBU/ODU/CUA, Q2/2022)
- Mechanical integration of initial hpDIRC prototype into CRT achieved (SBU/CUA/GSI, Q2/2022)
- Complete QA of bars from first disassembled BaBar DIRC bar box, decision about further disassembly strategy (ODU, Q3/2022)
- Initial DAQ and track reconstruction software ready and tested (CUA/SBU, Q3/2022)
- Prototype of readout electronics available for tests with small-pixel MCP-PMT in Hawaii (UH/Nalu, Q2/2022)
- Completed evaluation of cost/performance optimized EIC DIRC design options in simulation (CUA/GSI, Q4/2022)
- Start integration of first new small-pixel MCP-PMT/readout electronics modules into hpDIRC prototype at SBU (CUA/UH/Nalu, Q4/2022)

4 Preview of the remaining R&D for FY23 and FY24

The R&D effort in FY23 and FY24 will focus on the final development and study of the hpDIRC full system prototype to address remaining technical and cost risks. In FY23 we plan to perform tests of the hpDIRC prototype in the CRT and at Fermilab to validate the DAQ as well as the tracking and timing detectors and the associated reconstruction software. The goal is to ensure that the prototype configuration is capable of reaching the required resolution of the particle track and event time. The beam test will also allow a first test of the new sensor readout electronics at the occupancy and event rates available in a particle beam. In FY24 the final hpDIRC prototype configuration will evaluate the optimized sensor arrangement as well as the potential new focusing approach in the context of the hybrid design, combining a narrow bar and a wide plate. While this configuration would offer a significant cost reduction, it has not been experimentally studied so far, requiring experimental validation to decide on the final hpDIRC design.

5 FY22 Funding request

Item	**Institution**	**Requested**
Postdoc (50%) hpDIRC software	CUA	\$80k
Prototype Equipment	CUA	\$10k
Sensors for 2023 EIC hpDIRC Prototype (CUA)	CUA	\$140k
Travel to DIRC lab at SBU	CUA/GSI	\$30k
Postdoc (50%) QA of BaBar DIRC bars	ODU	\$80k
Equipment for QA of BaBar DIRC bars	ODU	\$50k*
*(in case direct funding from JLab is unavailable)		
CRT readout electronics	SBU	\$20k
CRT materials	SBU	\$15k
Postdoc (50%) readout electronics	UH	\$60k**
Test-bench/readout board assembly	UH	\$15k**
ASIC and engineering support	Nalu	\$25k**
**(funding for the hpDIRC electronics development may be coordinated via eRD109)		
Total		\$525k

Budget Per Institution:

Institution	CUA	ODU	SBU	UH	Nalu	**Total**
Requested	\$260	\$130k*	\$35k	\$75k**	\$25k**	\$525k